High Gain Fiber Amplifiers for DWDM and Metro Networks

N. Peyghambarian
Optical Sciences Center,
University of Arizona

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **18 APR 2000**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **High Gain Fiber Amplifiers for DWDM and Metro Networks**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Arizona**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
DARPA/MTO, WDM for Military Platforms Workshop held in McLean, VA on April 18-19, 2000, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

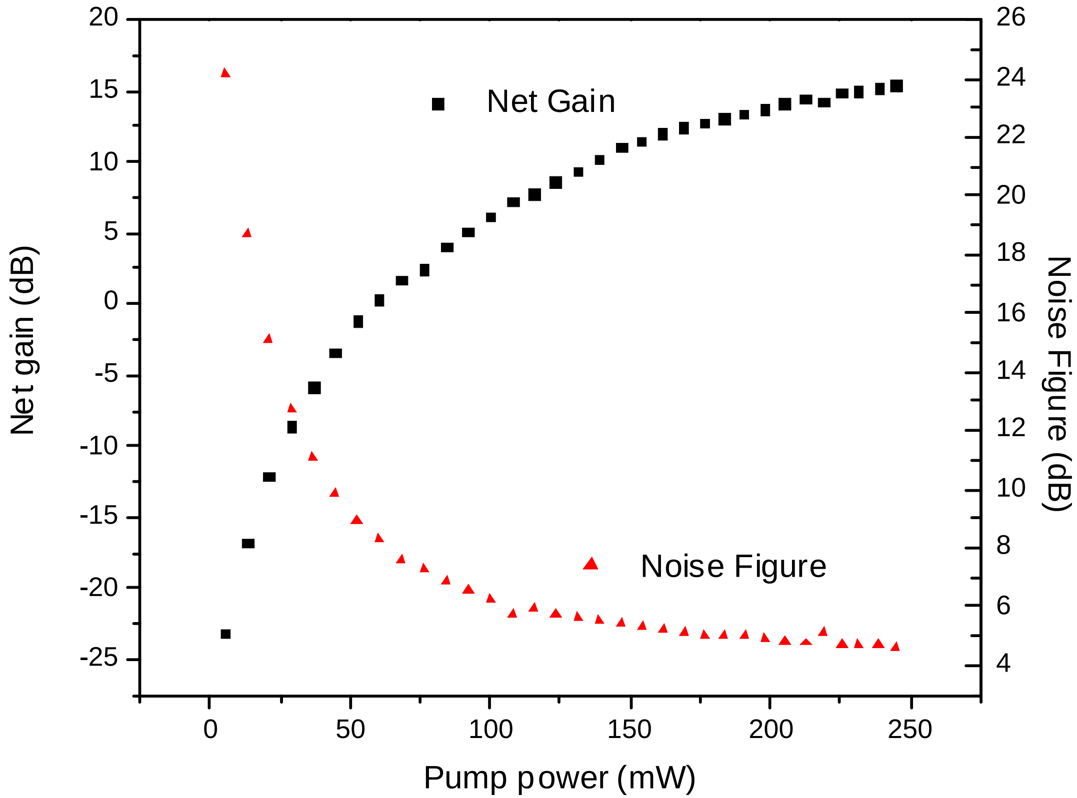
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**28**	

OUTLINE

- Motivation
- Glass and Fiber Fabrication
- Spectroscopic Characterization
- Gain Performance
- Conclusion

Amplifier Performance

Signal: 1534.9 nm at -31 dBm

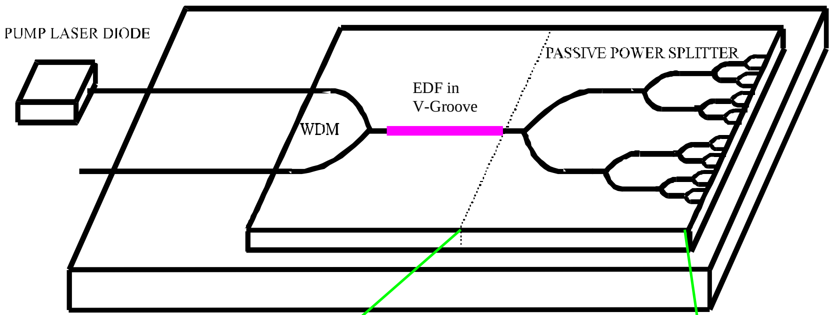


15.5 dB **net** gain for 5.1 cm fiber

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Motivation

Lossless Splitter



1x16 splitter: 15dB loss

Commercial EDFA
gain : 0.02dB/cm

Ultra Compact 1.54 μm Fiber Amplifier

↓

High Er^{3+} Doping Concentration

↓

Low Cooperative Upconversion Co.

↓

Phosphate Glasses

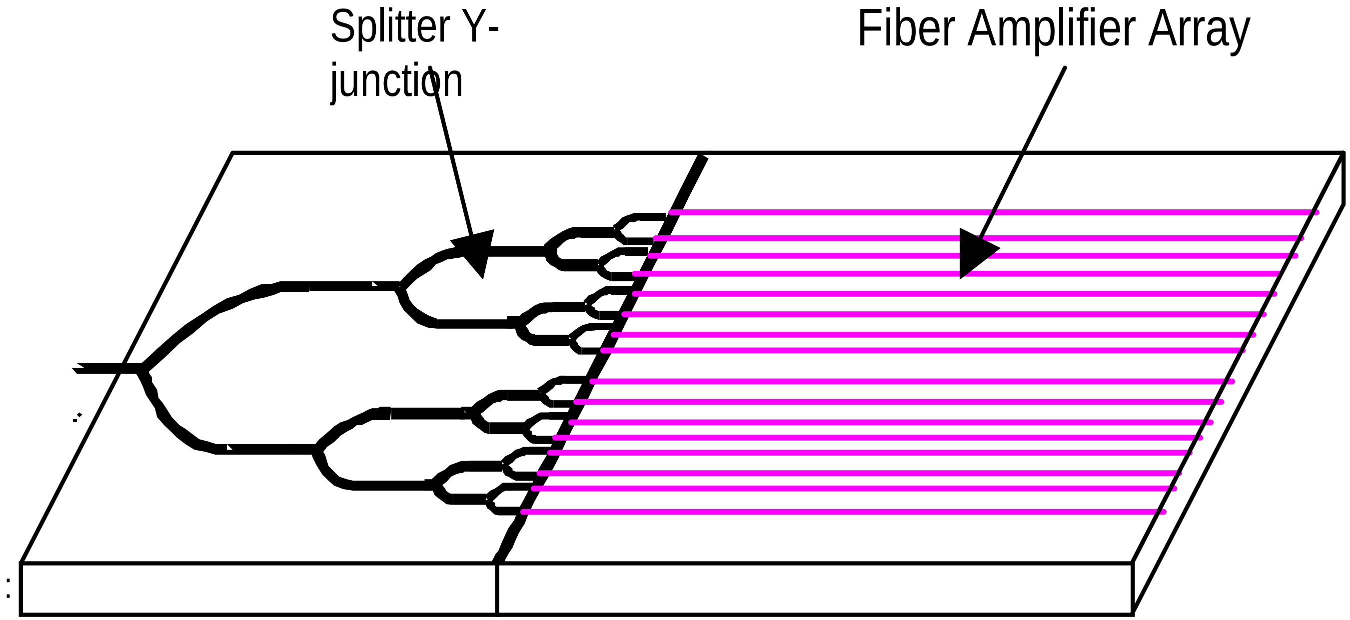
⇓

Phosphate Glass Fiber Amplifier

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

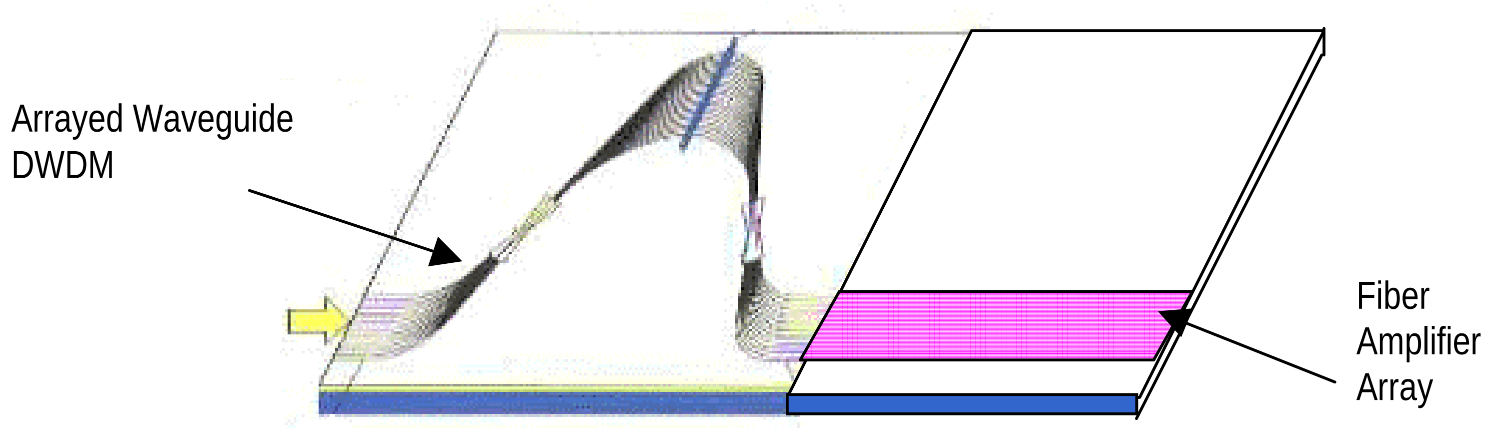
Amplifying Splitter

NP Integrated Power Splitter Concept



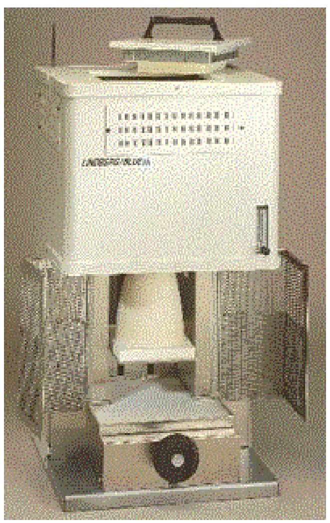
NP Amplifying Arrayed Waveguide Multiplexer

NP Arrayed Waveguide Multiplexer

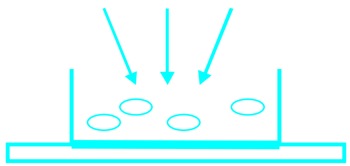


THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

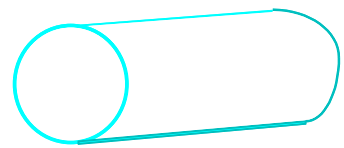
Glass Fabrication



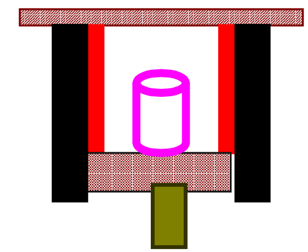
P_2O_5 Al_2O_3 R_2O, et al



Batch



Mixing

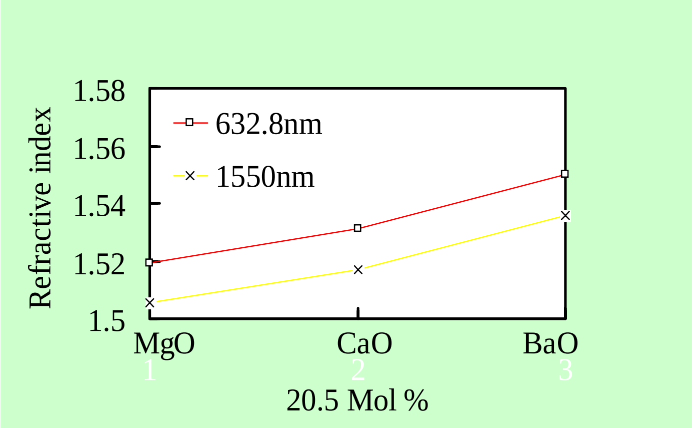


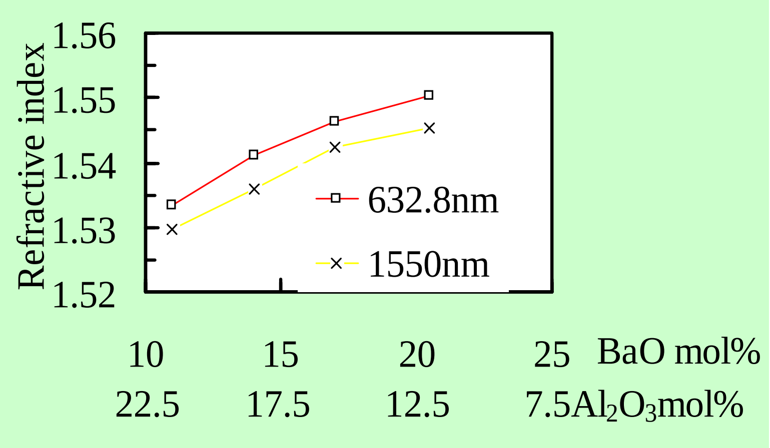
Melt

Cast | **Annealing** | **Inspection** | **Fabrication**

Influence of Glass Composition on Refractive Index

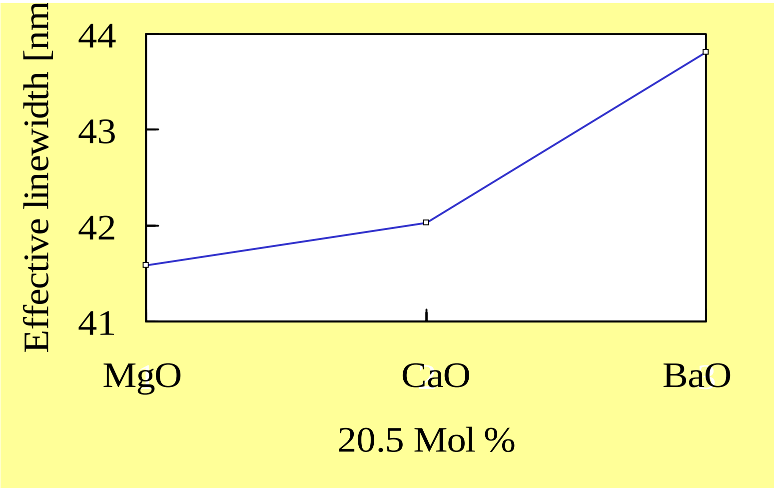
Glass type	Glass composition (Mole %)					
	P_2O_5	Al_2O_3	La_2O_3	MgO	CaO	BaO
P1	64	12	3.5	20.5		
P2	64	12	3.5		20.5	
P3	64	12	3.5			20.5
P4	64	15.5	3.5			17
P5	64	18.5	3.5			14
P6	64	21.5	3.5			11

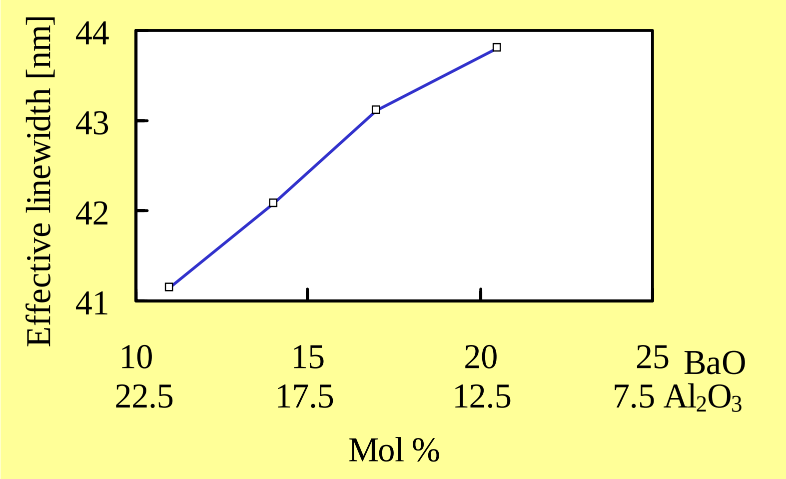




APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

Influence of Glass Composition on Effective Linewidth of Er^{3+} $^4I_{13/2}$ - $^4I_{15/2}$ Transition



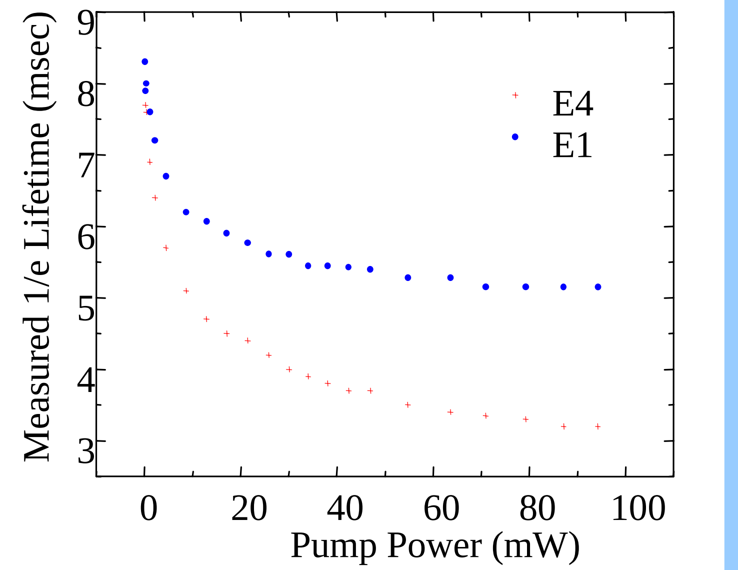


Effective Line width of the 1.54 µm transition

$$\Delta\lambda_{eff} = \frac{\int \alpha(\gamma)\,d\gamma}{\alpha_{peak}}$$

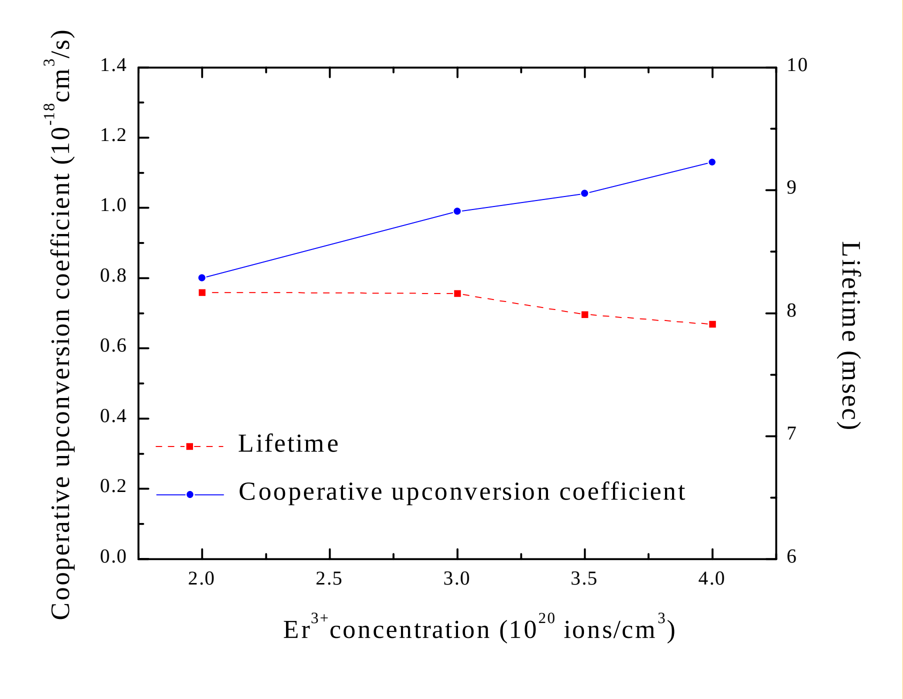
Measured 1/e Lifetime of Er^{3+} Ions

Samples	Er^{3+} concentration (ions/cm^3)	Yb^{3+} concentration (ions/cm^3)
E1	2.0×10^{20}	0
E2	3.0×10^{20}	0
E3	3.5×10^{20}	0
E4	4.0×10^{20}	0
YE1	2.0×10^{20}	2.0×10^{20}
YE2	2.0×10^{20}	4.0×10^{20}
YE3	2.0×10^{20}	6.0×10^{20}



THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

Cooperative Upconversion Coefficient and Spontaneous Lifetime



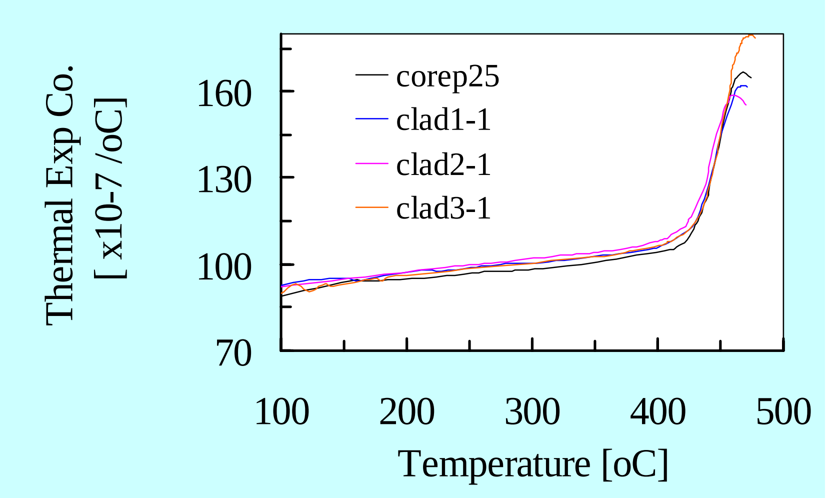
$$N_{E2}(t) = \frac{1}{\tau_E^o}\left[\left(\frac{1}{\tau_E^o N_{E2}(0)} + C\right)\exp\left(\frac{t}{\tau_E^o}\right) - C\right]^{-1}$$

$$N_{E2}(0) = \frac{R_{E13}\tau_E^o + 1}{2C\tau_E^o}\left(\sqrt{1 + \frac{4CN_E R_{E13}\tau_E^o}{R_{E13}\tau_E^o + \tau_E^o}} - 1\right)$$

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

Cladding Glasses

Glass type	Refractive index			
	632.8 nm	830 nm	1300 nm	1550 nm
Core P25	1.5431	1.5389	1.5318	1.5290
Cladding1-1	1.5365	1.5309	1.5249	1.5217
Cladding2-1	1.5298	1.5250	1.5187	1.5158
Cladding3-1	1.5257	1.5206	1.5150	1.5116



$\Delta n/n_1$=0.48% ~1.14%,
NA=0.149 ~ 0.230

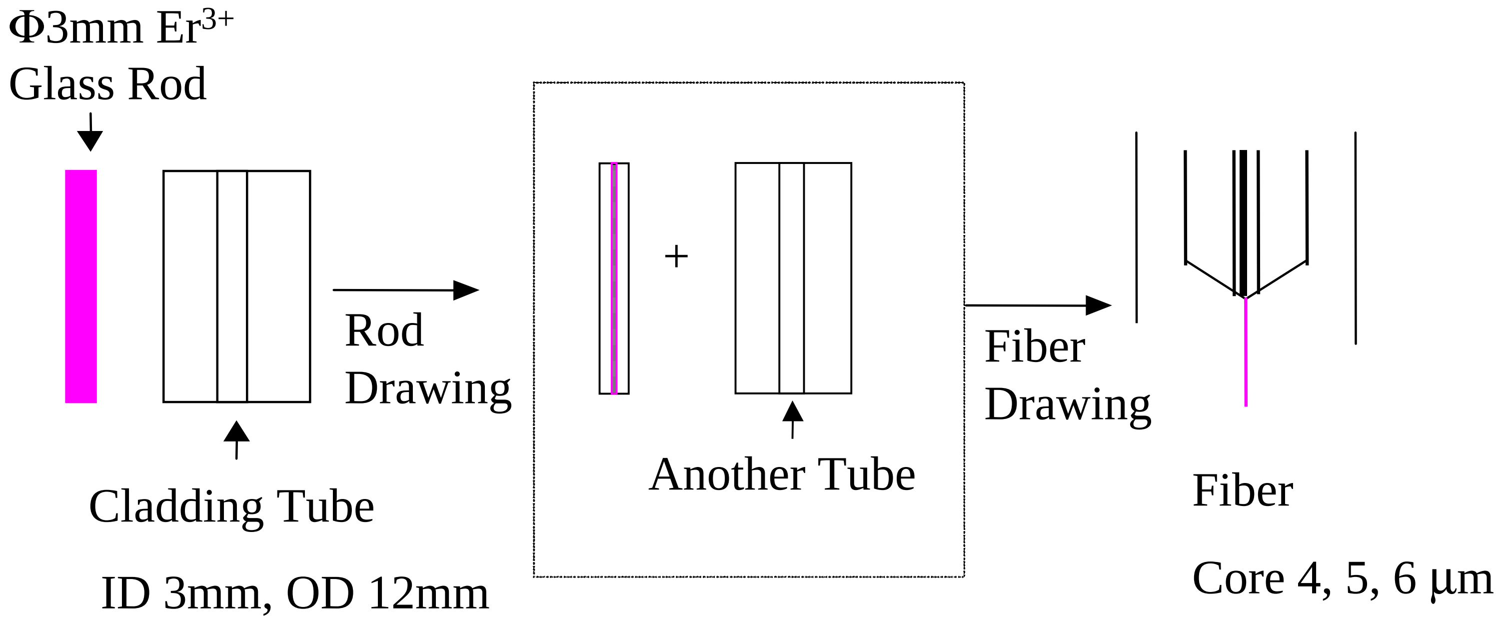
$\Delta\ \alpha/\alpha_1 < 3\%$

$\Delta\ T_g/T_{g1} < 1\%$

$\Delta\ T_f/T_{f1} < 3\%$

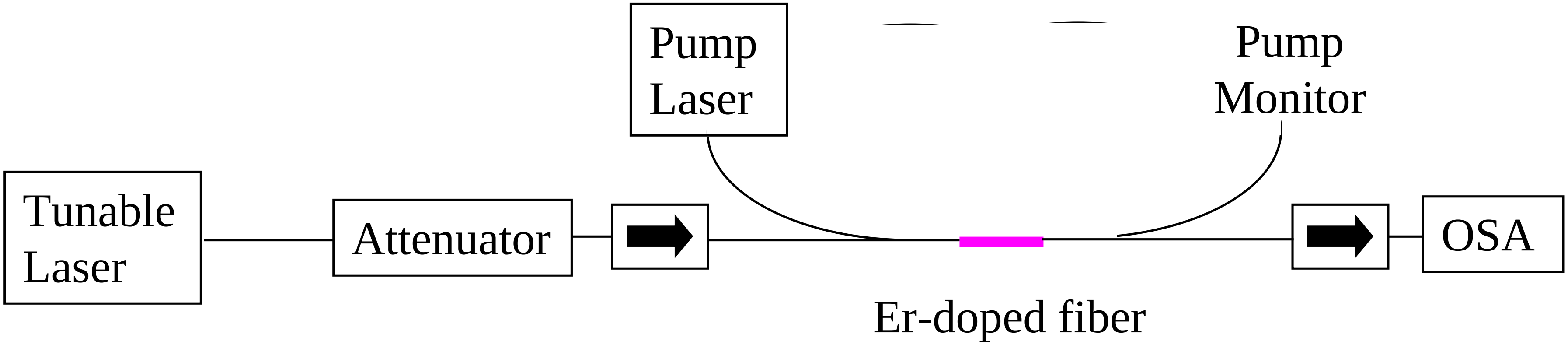
Fiber Drawing

Rod-in-tube technique



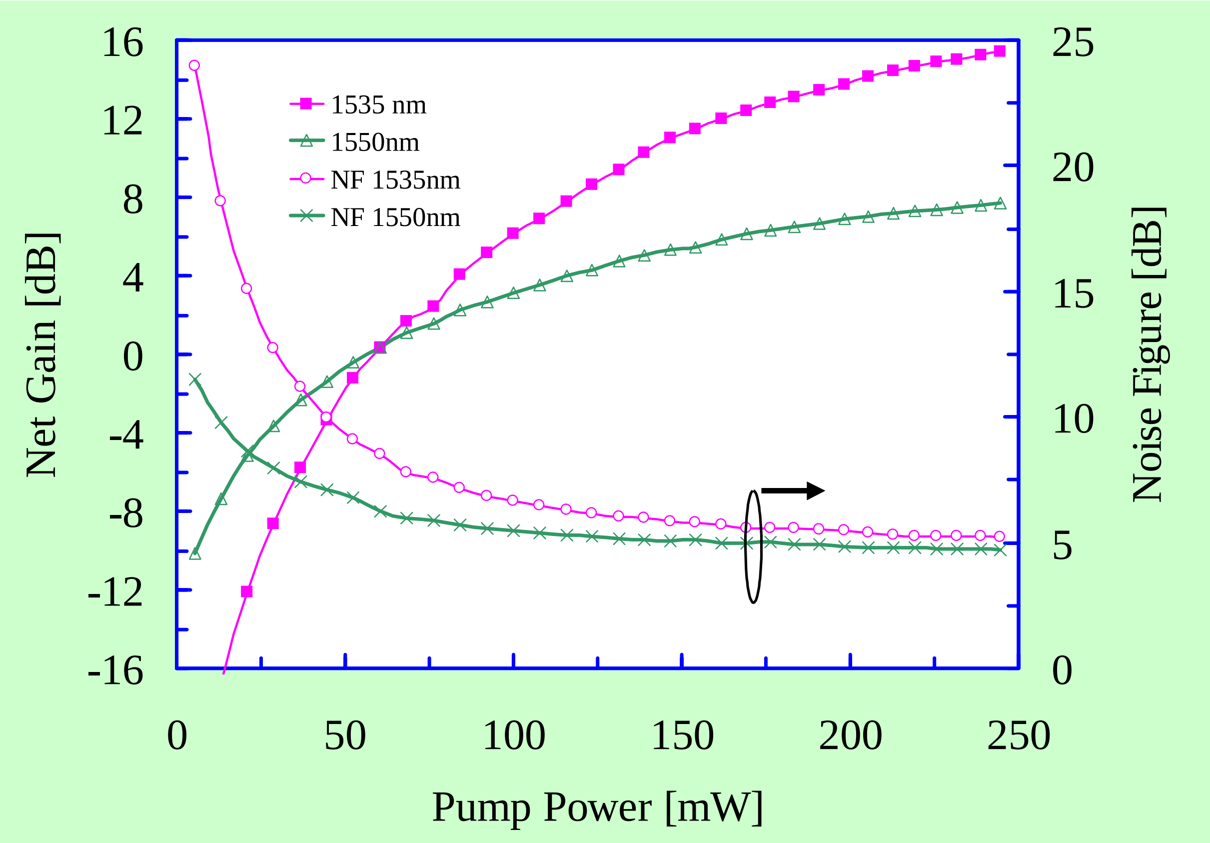
Core Diameter: 4-6 μm

Experimental Setup for Gain Measurement



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

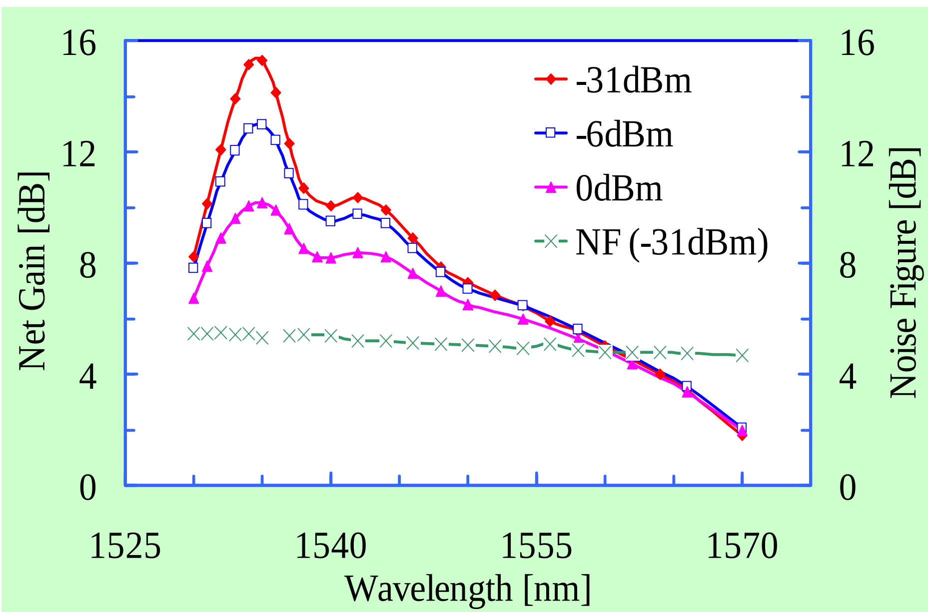
Gain Characteristics

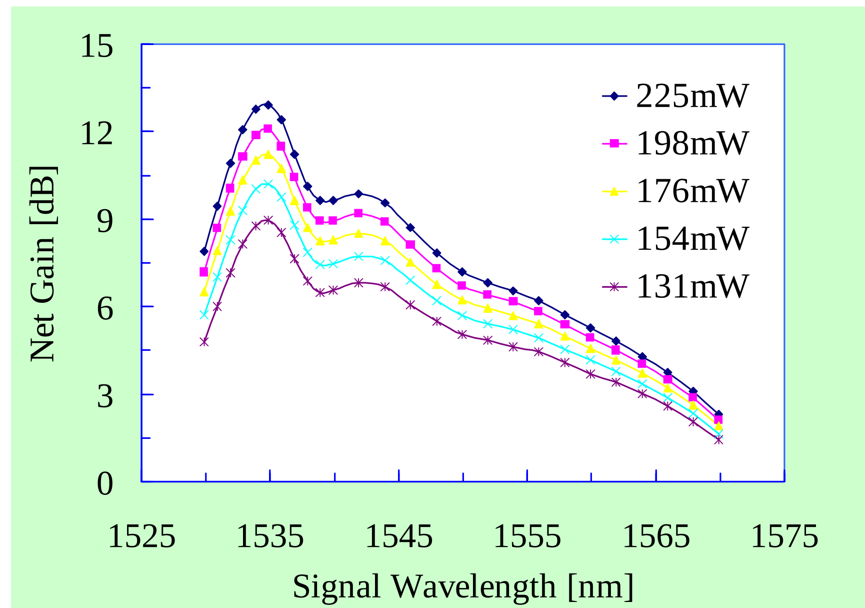


Fiber Length:

5.1cm

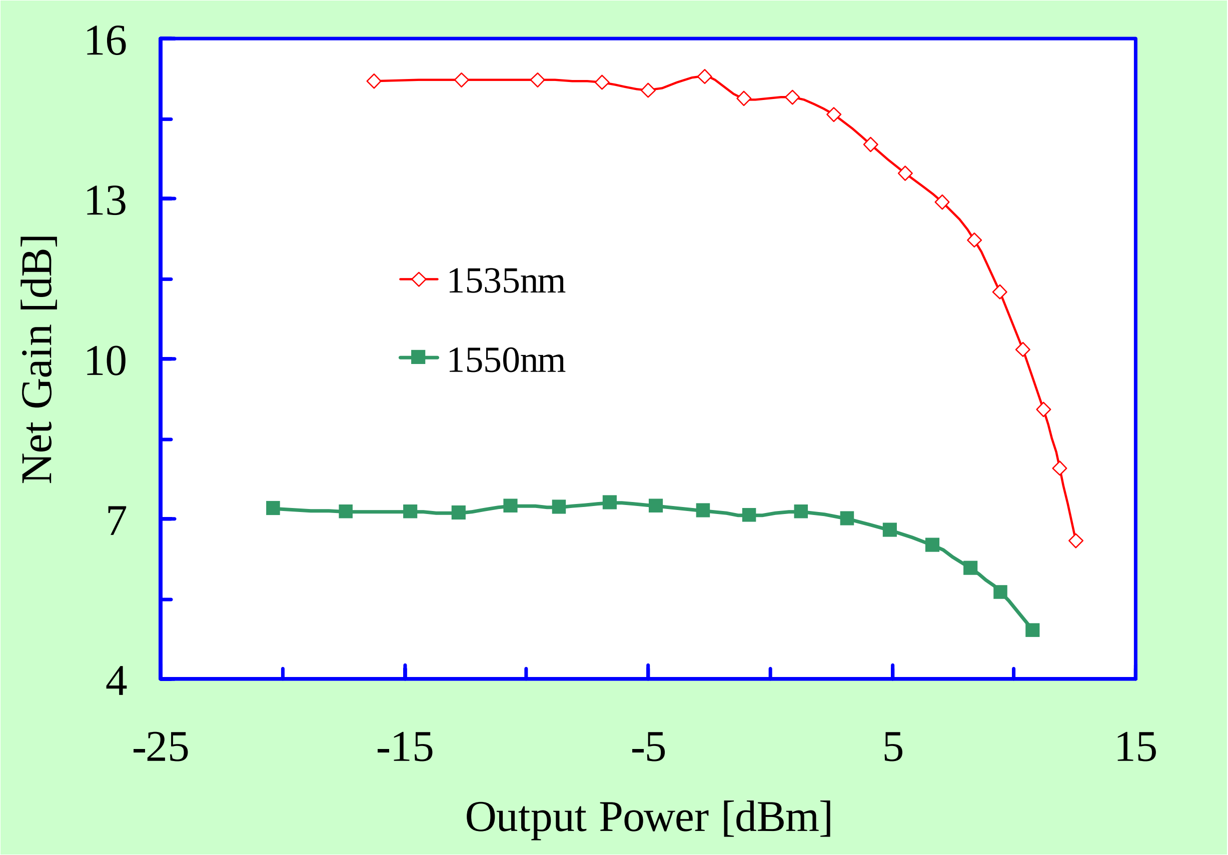
Gain Spectrum





The University of Arizona
Tucson Arizona

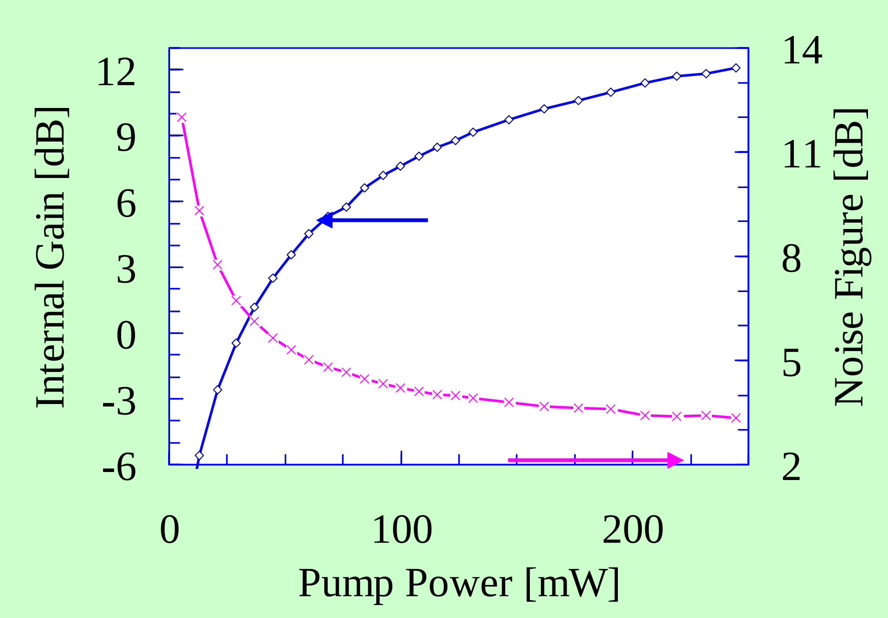
Gain Saturation

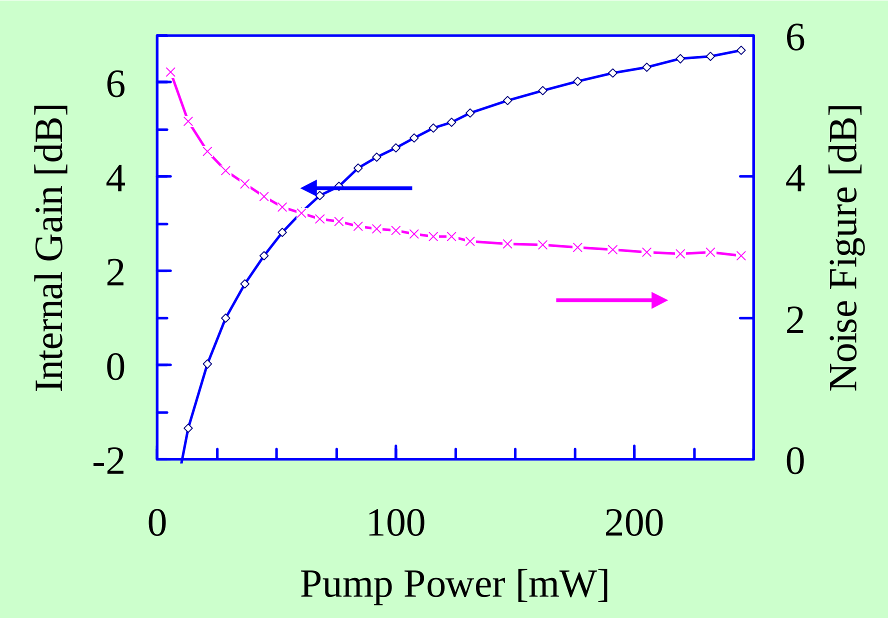


APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

Gain Performance





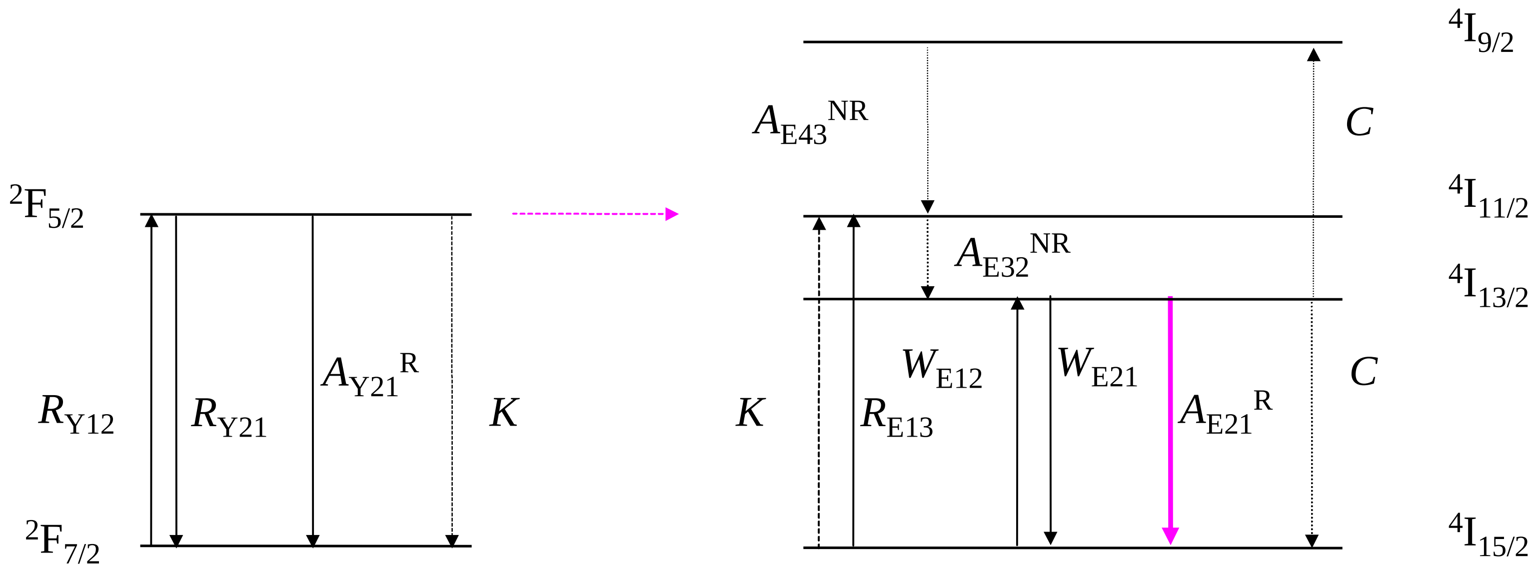
1535nm, -31.6dBm

3.2cm-long fiber

1550nm, -31.6dBm

3.2cm-long fiber

Spectral Properties



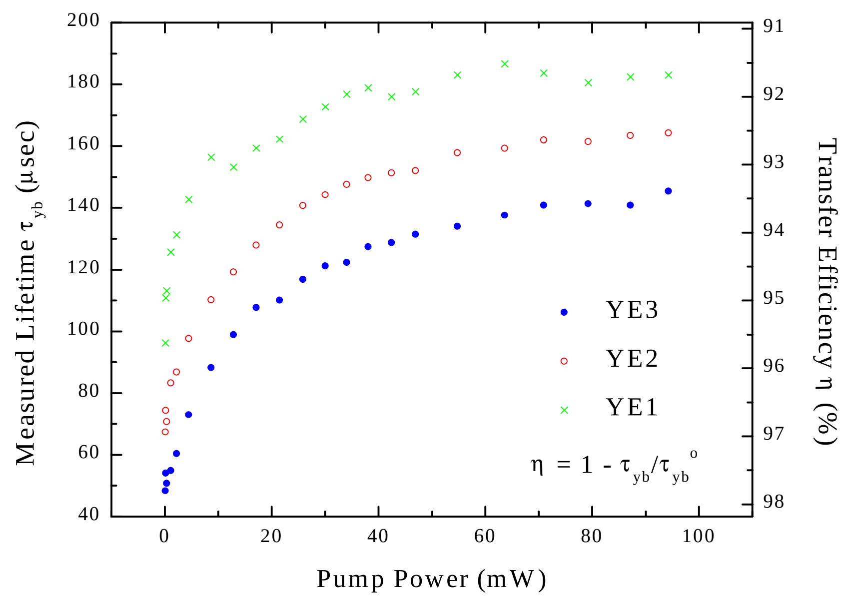
Yb^{3+} ions

Er^{3+} ions

Energy Levels of Er^{3+} and Yb^{3+} Ions

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

Energy Transfer Efficiency



Efficiency

$$\eta = 1 - \frac{\tau_{Yb}}{\tau_{Yb}^{o}}$$

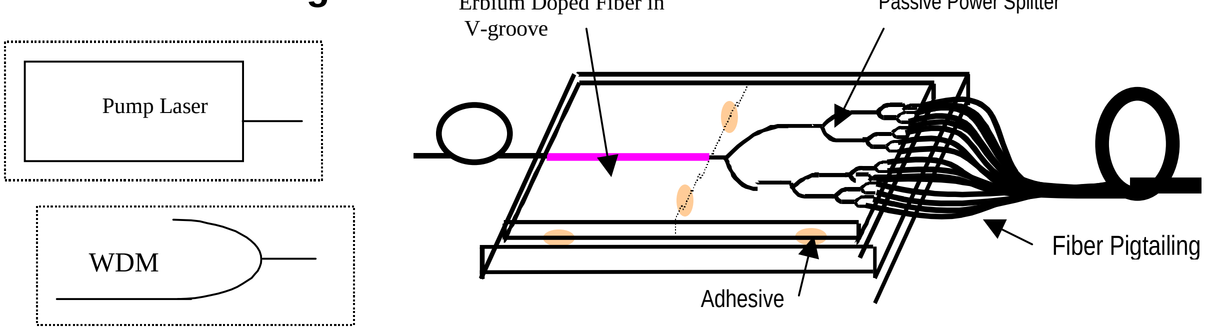
τ_{Yb}^{o} Lifetime without Er^{3+} ions

τ_{Yb} Measured lifetime

Amplifying Splitter (and Combiner)

One Input Port and Multiple Ourput Ports (n) for
Amplifying and Dividing Optical Signals Near 1.54 µm

Technical Drawing



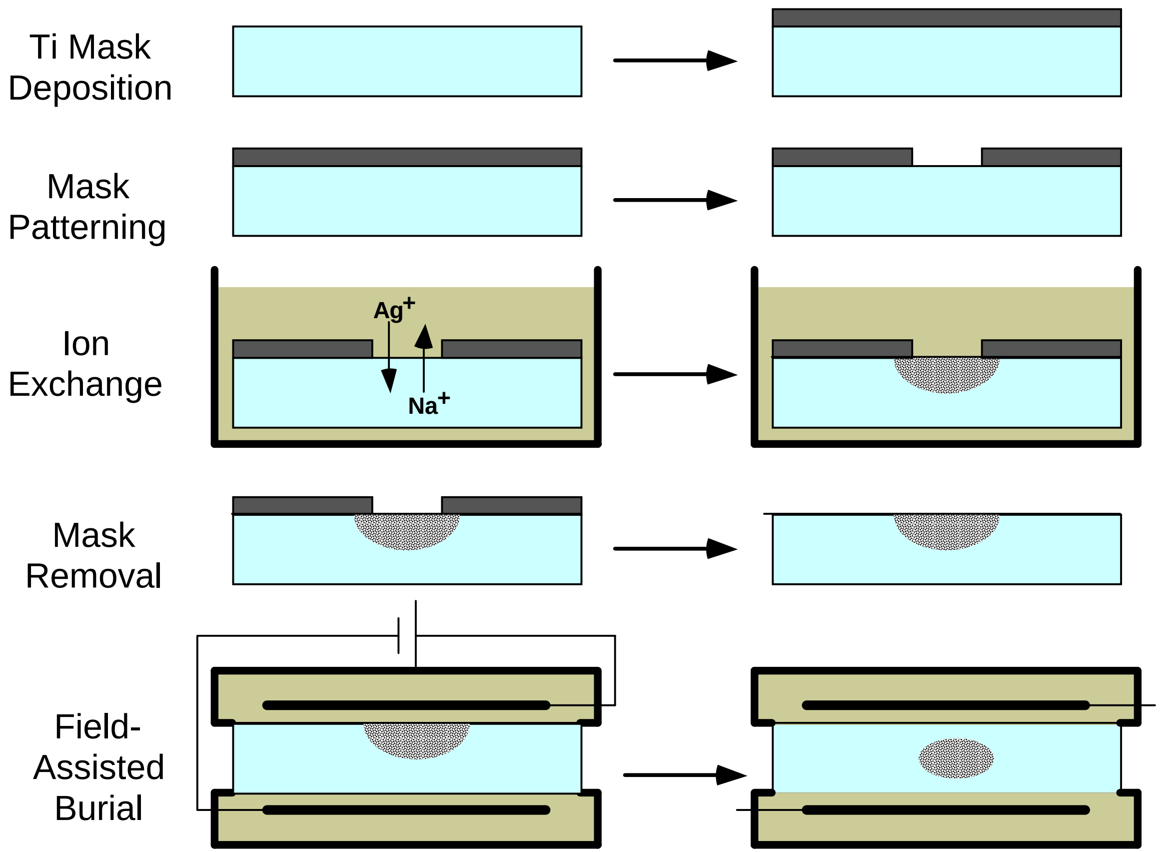
Packaged Product:

Aluminum Case Size
(1 x n: L x W x H mm^3)
1x04: 95 x 11 x 6.5
1x08: 95 x 11 x 6.5
1x16: 115 x 11 x 7
1x32: 150 x 16 x 7

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

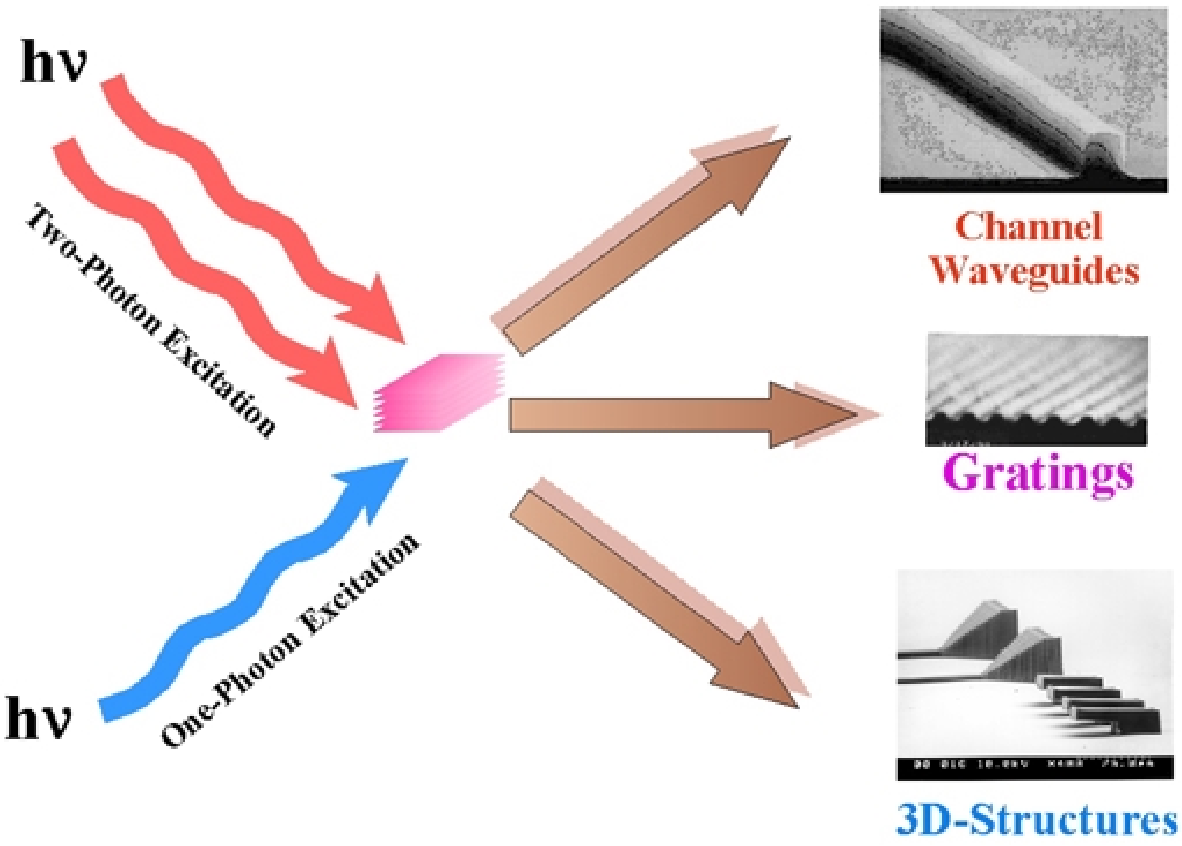
THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

Ion-Exchanged Waveguide Fabrication



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

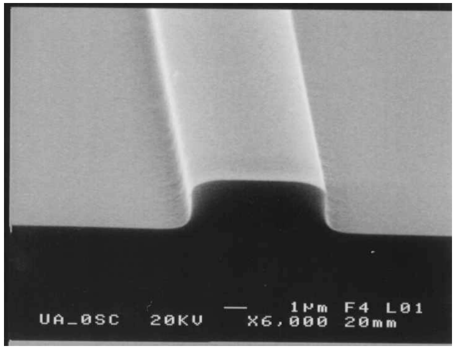
Photoimagable Hybrid Materials

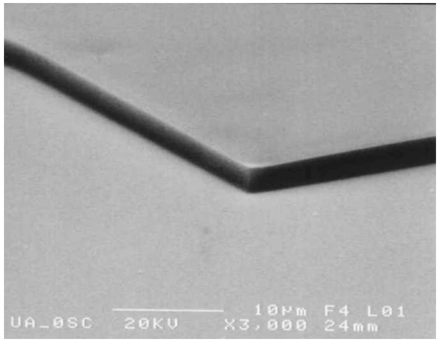


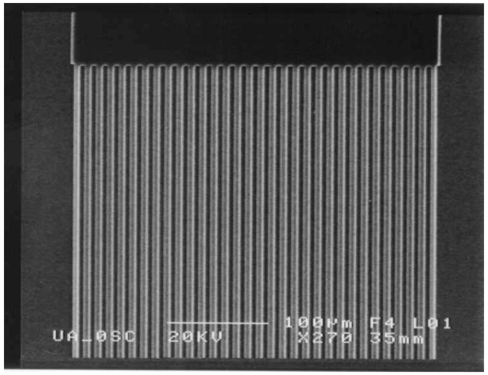
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

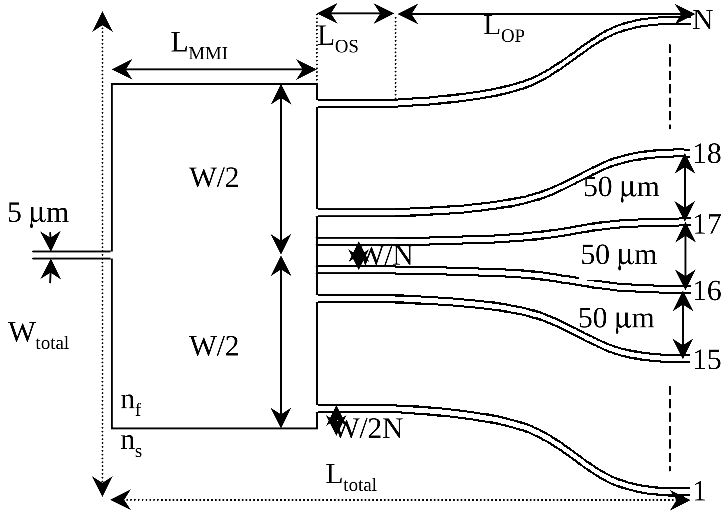
THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

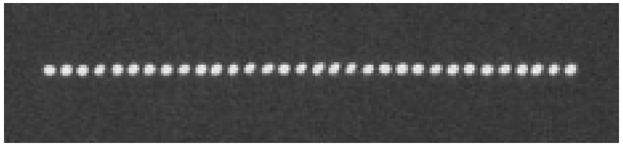
1-N Sol-Gel MMI Splitter











1x32 MMI output

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Conclusions

- Er^{3+}-doped phosphate glasses
- Single mode phosphate glass fiber
- Phosphate glass fiber amplifier
- 15.5dB net gain from a 5.1cm fiber

Modify glass composition to improve gain spectrum

Dope Yb to improve gain efficiency

Optimize fiber design to increase the gain

Improve coupling loss to reduce the NF

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Acknowledgment

Assistant Research Professor: Shibin Jiang

Ph.D. Students: Bor-chyuan Hwang
Yongdan Hu
Karine Seneschal

Post-doctor: Dr. Jerome Porque

Research Scientist: Dr. Yong Ding

Visiting Scholar: Dr. Gino Sorbello (Politecnico di Milano, Italy)

Collaborator : Dr. Tao Luo (NP Photonics Technologies LLC)
Dr. Seppo Honkanen (NP Photonics Technologies LLC)
Prof. Fred Smektala (Universite de Rennes 1)
Prof. Jacques Lucas (Universite de Rennes 1)

Acknowledgment

BMDO through the SBIR Phase II program

NP Photonic Technologies, LLC

UA Science and Technology Park
9030 South Rita Road, Suite 120, Tucson,
Arizona 85747

THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

Parameters of Single Mode Fiber

Core diameter	5 μm
Refractive index of cladding glass at 1.535 μm	1.5170
Refractive index of core glass at 1.535 μm	1.5327
Numerical aperture	0.219
Cut-off wavelength	1.43 μm
Attenuation	<0.3dB/cm
Er^{3+} concentration	35000ppm